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Cloud Feedback and ENSO from A-Train

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2018 CloudSat/CALIPSO

Cloud Feedback Definition(s)

The change of global mean cloud-induced radiative anomalies (ΔR_G) at TOA in response to 1K change in global mean surface temperature (ΔT_{GS}).

$$\lambda_{GG}(c) = \frac{\Delta R_G(c)}{\Delta T_{GS}} = \frac{\overline{\Delta R(c,\phi)}}{\Delta T_{GS}}$$

- Long-term climate change, λ_{GG} is a measure of cloud contribution to the stability of global climate with respect to forcing.
- On shorter time scale or transient warming: varies with time

Consider energy balance at local scale (e.g. Armour 2013, Rose et al. 2014)

$$\lambda_{LL}(c,\phi) = \frac{\Delta R(c,\phi)}{\Delta T_S(\phi)},$$

$$\lambda_{GG}(c) = \overline{\lambda_{LL}(c,\phi)\frac{\Delta T_S(\phi)}{\Delta T_{GS}}}$$

- λ_{LL} (nearly) time-invariant?
- If so, temporal variability is mainly coming from the response of local surface temperature to the global mean surface temperature change (e.g. Armour 2013).

Still the local feedback concept, as in Zhou et al. (2017):

$$\lambda_{GL}(c,\phi) = \frac{\Delta R_G(c)}{\Delta T_S(\phi)} = \overline{\Delta R(c,\phi)} \Big/ \Delta T_s(\phi)$$

- Local feedback shows strong temporal variability.
- the scaling relationship cannot reconstruct the global cloud feedback.

$$\lambda_{GG}(c) = 1 \Big/ \overline{\left(1/\lambda_{GL}(c,\phi)\right)}$$

Importance of Observation Constraints

Observations: short record, uncertainty from various sources

Cloud Radiative Kernel (CRK) Method to Calculate Cloud Feedback by Cloud Type

$$CRF = F_{clr} - F_{all\_sky} = C(F_{clr} - F_{ovc}).$$

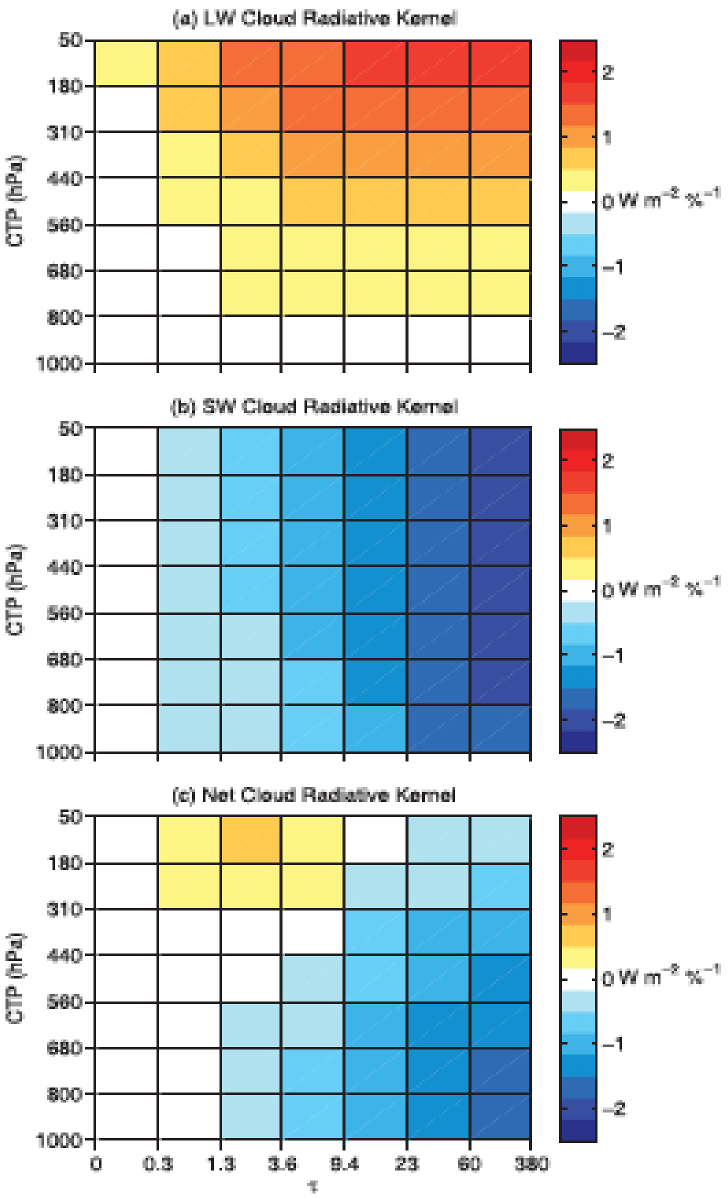
CRF: Cloud Radiative Forcing
C: Cloud fraction
F_{clr}: clear-sky TOA flux F_{ovc}: overcast-sky TOA flux

$$K \equiv \partial CRF / \partial C$$

K: Cloud Radiative Kernel, sensitivity of TOA radiation to cloud.

First proposed by Zelinka et al. (2012) to determine directly the cloud feedback by ISCCP CTP-τ cloud types

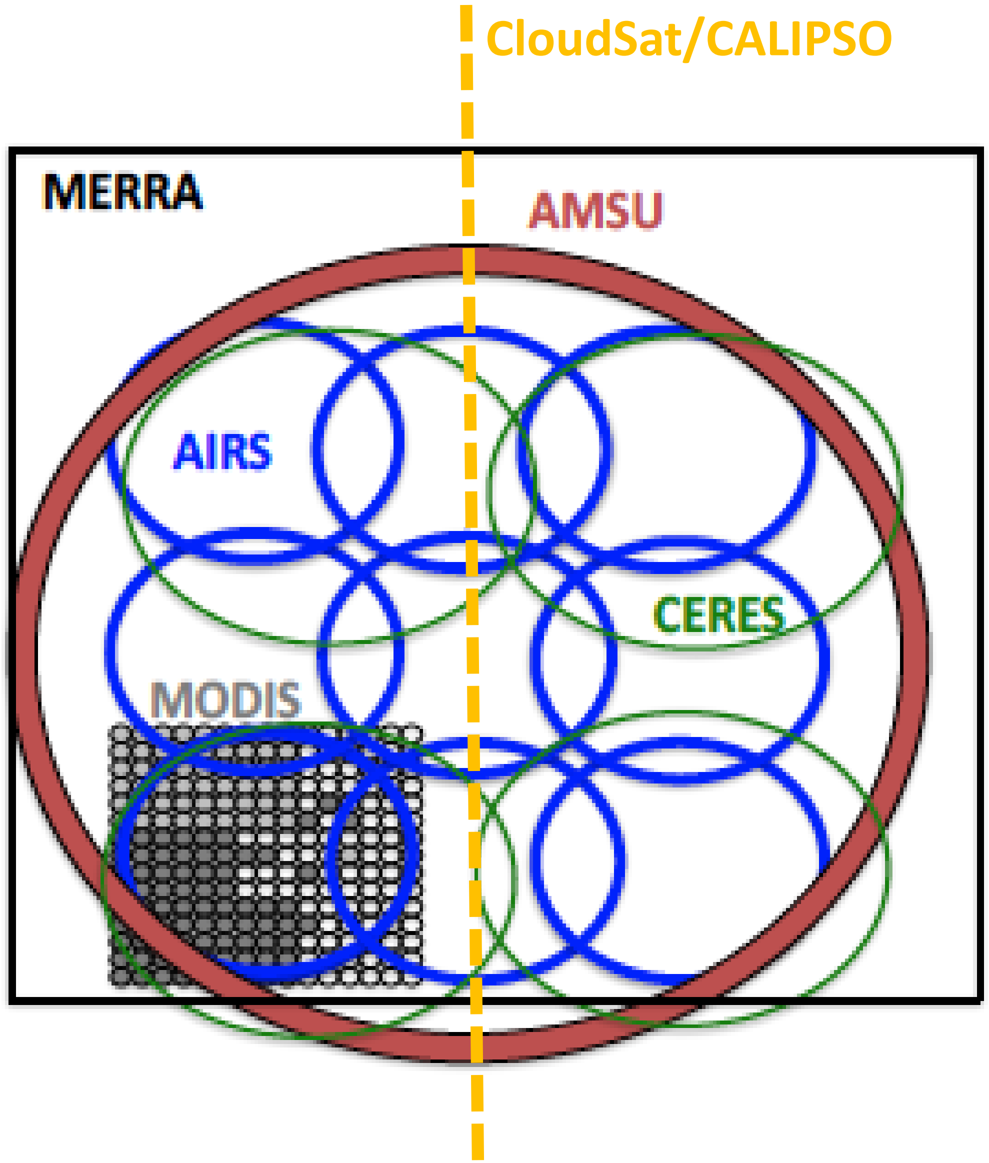
- Cloud type defined as ISCCP CTP-τ histogram
- Fu and Liou model.
- Zonal and monthly mean T and Q profiles from control runs of 6 GCM
- Assuming plane parallel single-layer overcast cloud, with synthetic cloud and surface properties.
- "Clear sky": cloud-removed.



Apply the traditional kernels directly to satellite observed (retrieved) cloud data record.

1. Clouds in observations are different from those in models.
2. Consistency between kernels and the response term.
3. A-Train measures radiation, cloud, and atmosphere simultaneously.

Pixel-scale Collocated Multi-Satellite Obs. and Reanalysis



- Cloud: MODIS (1km and 20km)
- TOA Radiation: AIRS (13km), CERES (20km)
- TOA Clear-Column Radiation: MERRA (1/2 X 2/3, hourly) , AIRS-Calculated (50km)
- Atmosphere and Surface: AIRS/AMSU (50km), MERRA
- Vertical profiles of cloud and radiative heating: CloudSat/CALIPSO (1.4 X 1.7km)

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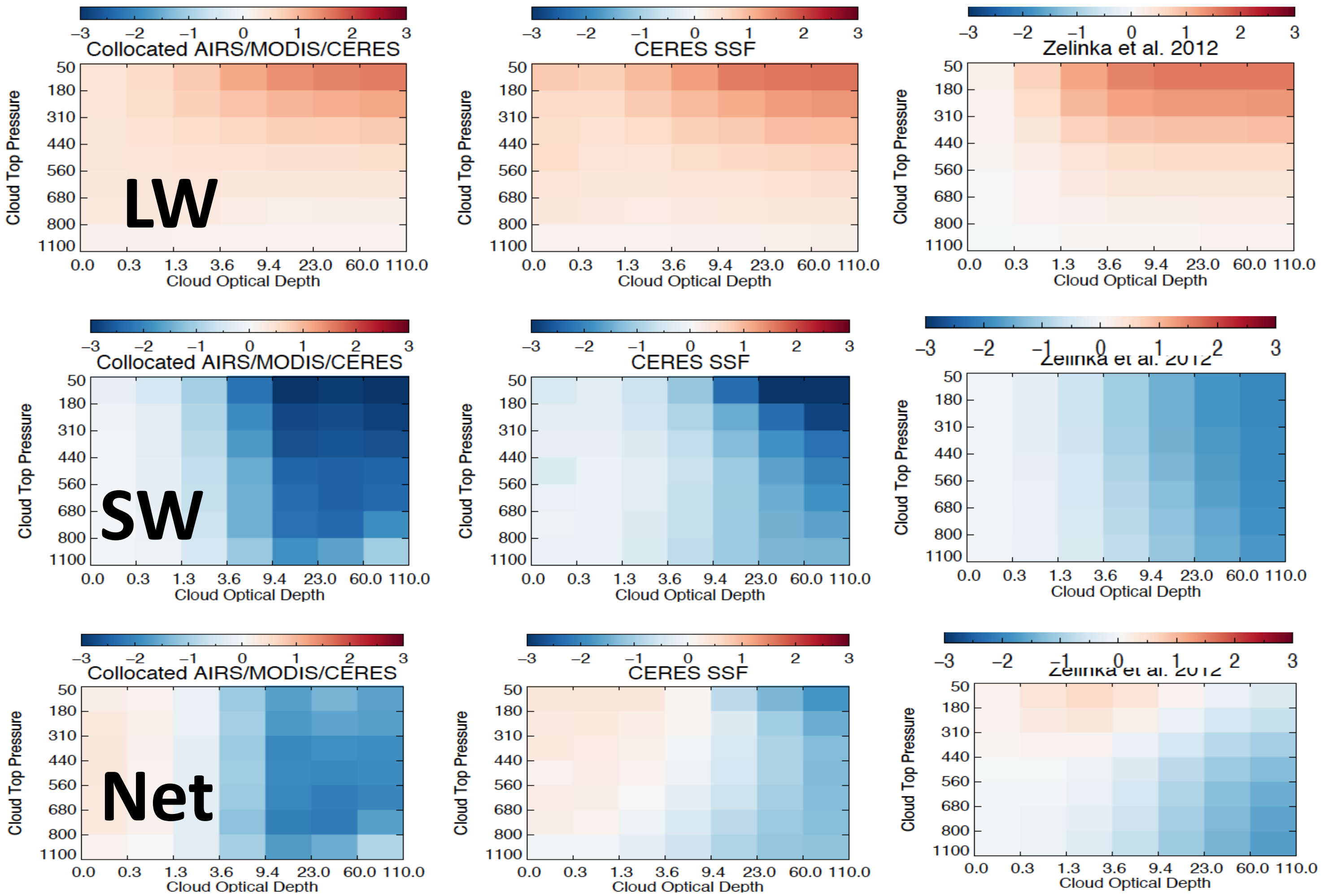
Observation-based Cloud Radiative Kernel

1. Standard MODIS cloud (MAST-MODIS), CERES flux, AIRS ECF.
2. CERES flux and CERES-MODIS cloud.
3. AIRS spectral longwave CRK.

Definition of clear sky: Observed clear: AIRS ECF< 0.01

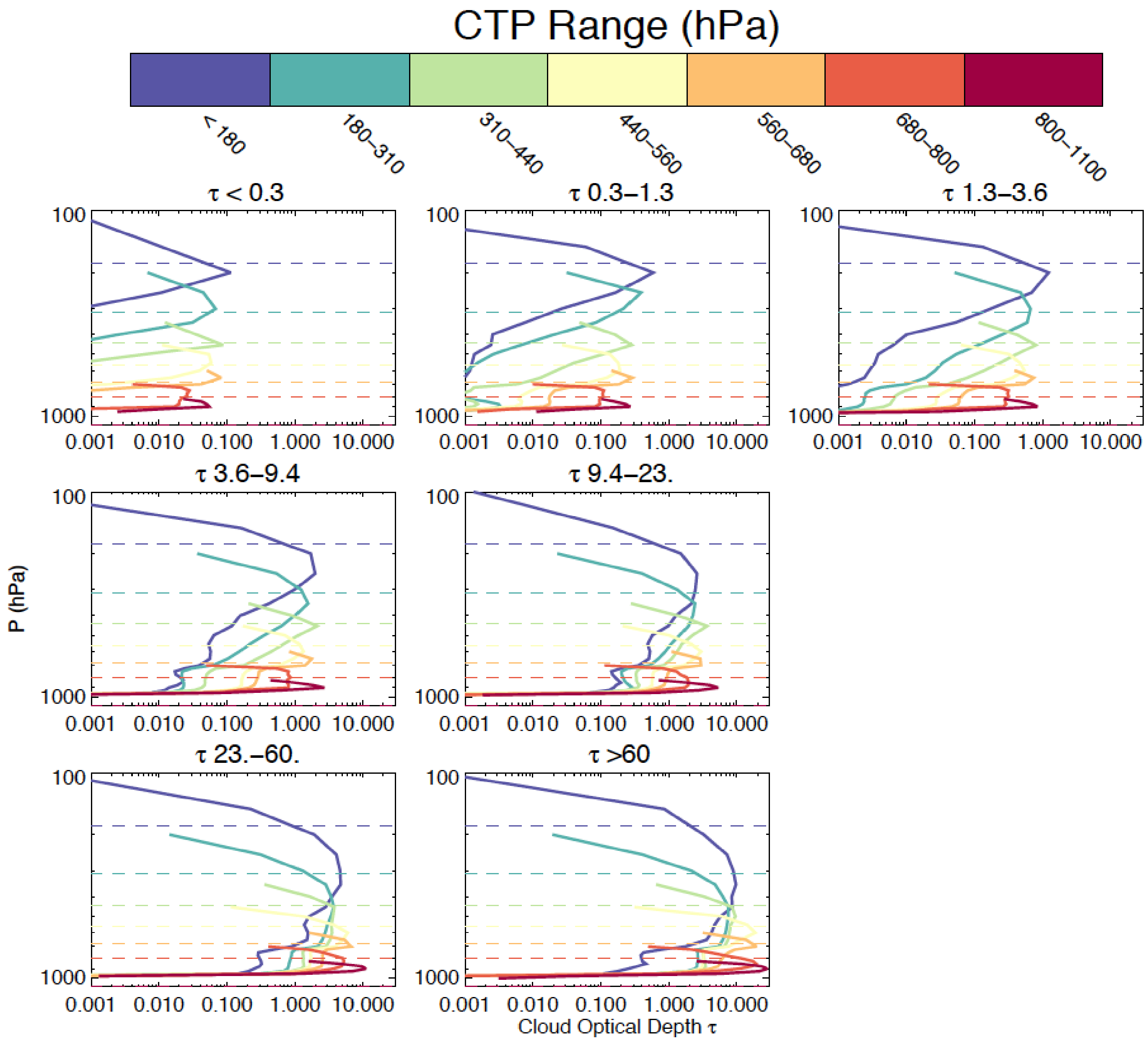
$$CRK = \frac{\partial CRF}{\partial C} = \frac{CRF}{C} = \frac{F_{clr} - F_{all-sky}}{C}$$



CRK ($Wm^{-2}\%^{-1}$) obtained by different data and methods (Yue et al. 2016a). Left: obs-CRK using the AIRS/MAST-MODIS/CERES data. (middle): obs-CRK using the AIRS/CERES-MODIS/CERES data. (right): CRK as in Zelinka et al. (2012).

Yue et al. 2016

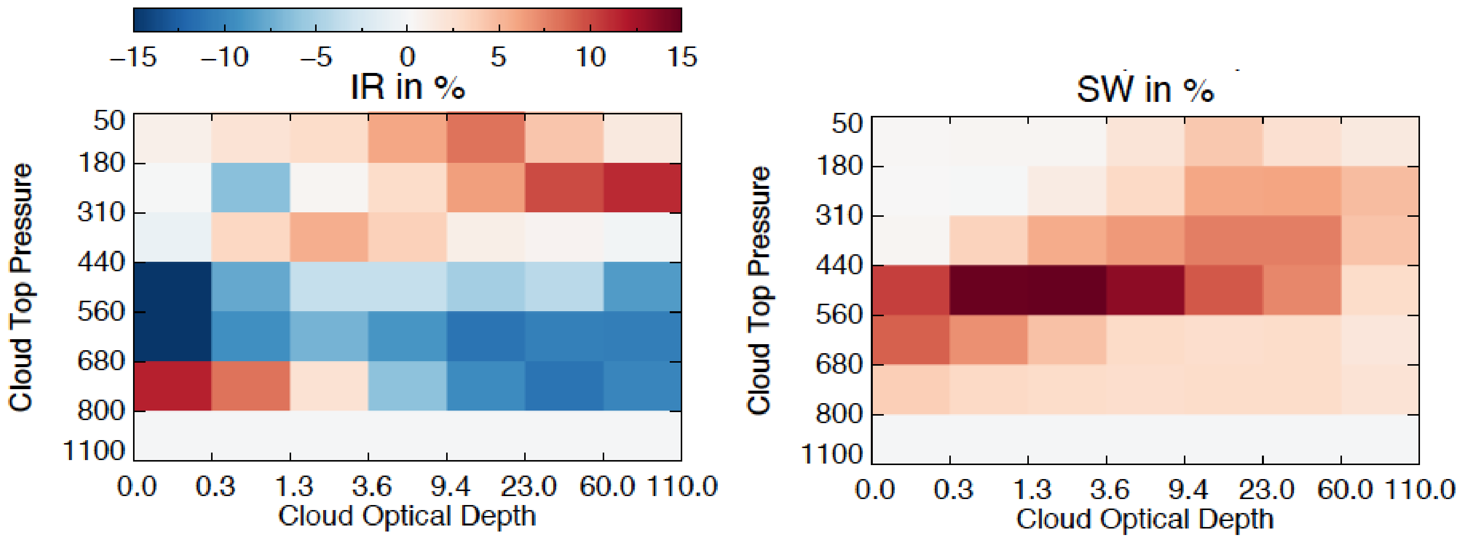
Vertical Distribution of Cloud Optical Depth



Mean optical depth vertical profiles by cloud type from collocated CloudSat/CALIPSO and MODIS data.

Cloud type is determined by MODIS.

Sensitivity of CRK to the Vertical Distribution of Cloud



CRK calculated assuming single-layer minus the result assuming multiple-layer cloud

Possible reasons:

SW: multiple scattering

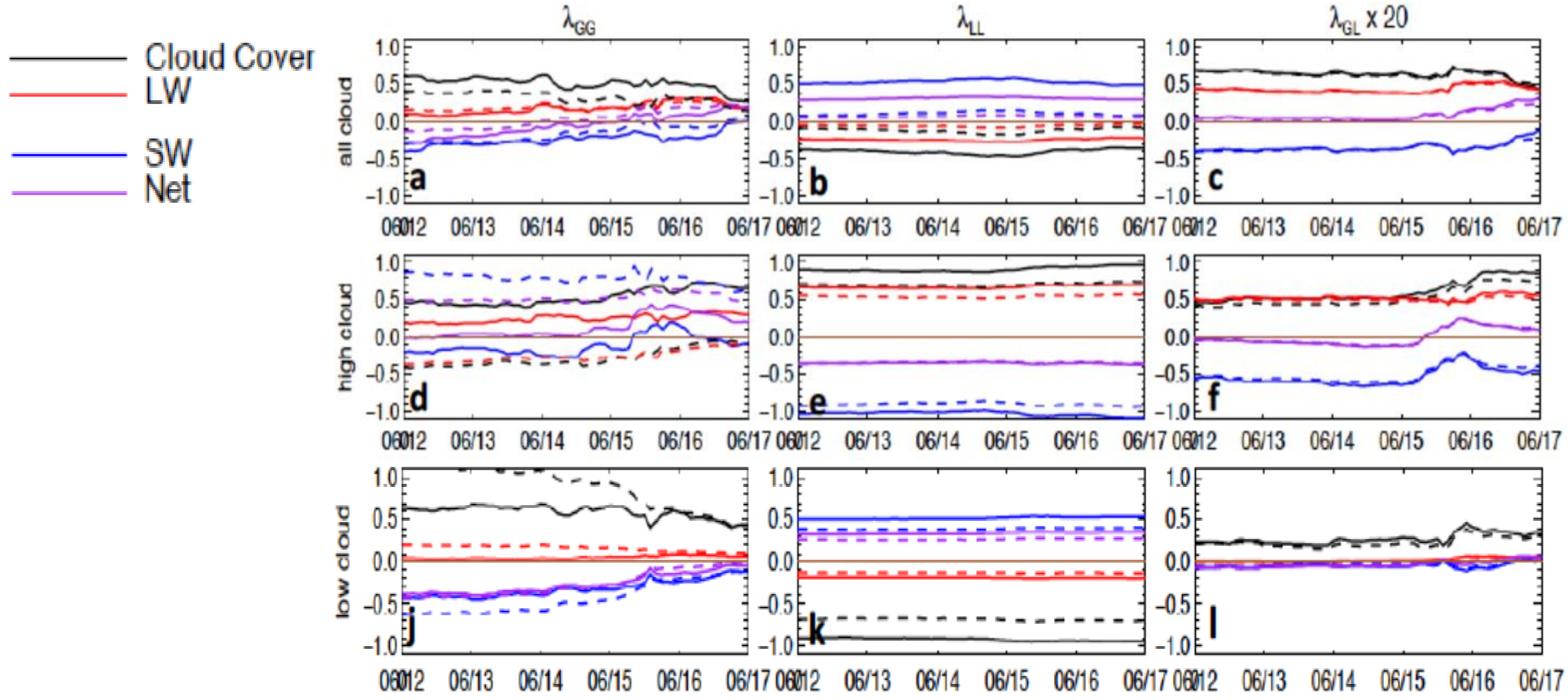
cloud with a vertical distribution has larger multiple scattering which increases the reflected SW radiation, resulting a more negative SW CRK.

LW: multiple scattering and cloud top temperature.

For high cloud, the cloud top determined by CO_2-slicing method is closer to the edge of the cloud, which is generally higher than the radiatively-effective cloud top, thus producing a smaller OLR than calculations assuming single layer cloud and a larger LW CRK.

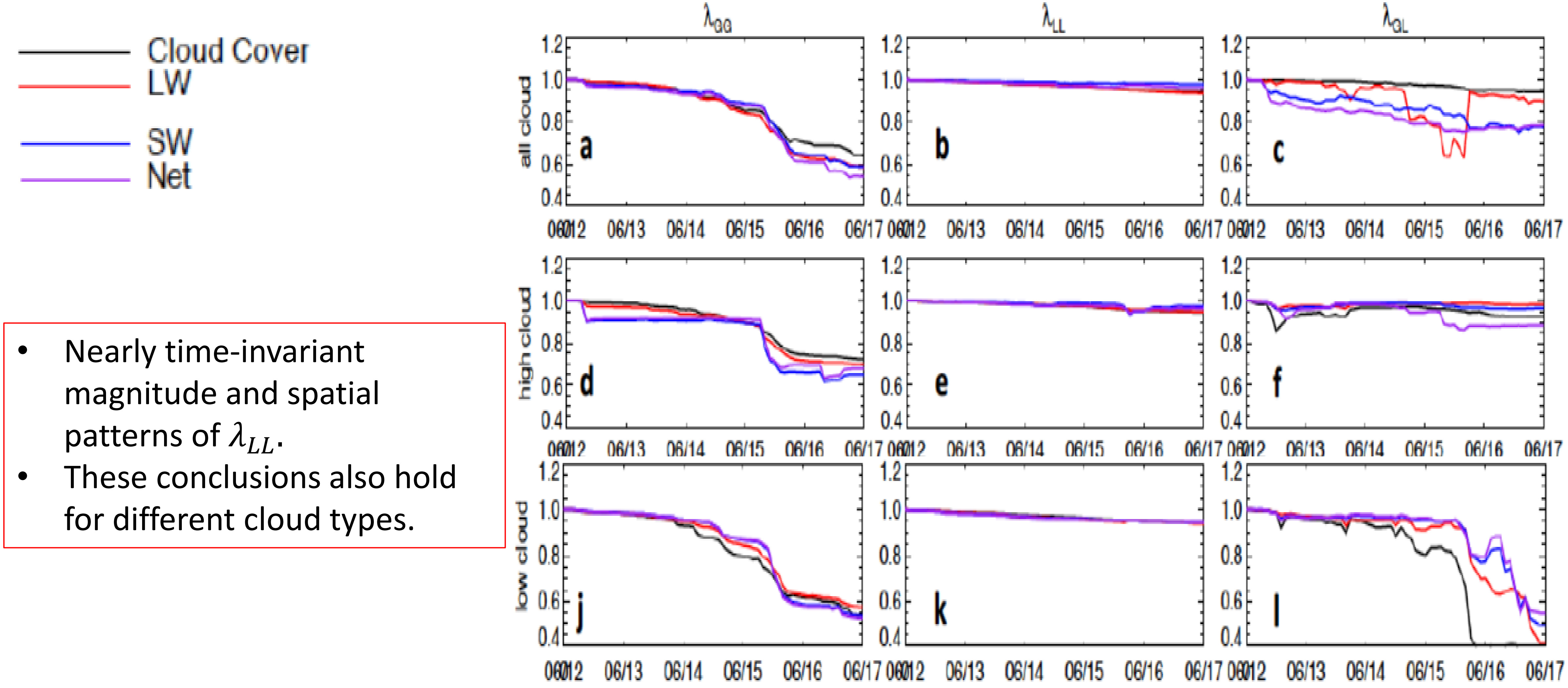
For low cloud, multiple scattering enhances the OLR.

Cloud Feedback to Interannual Climate Variability during the A-Train Era: Magnitude



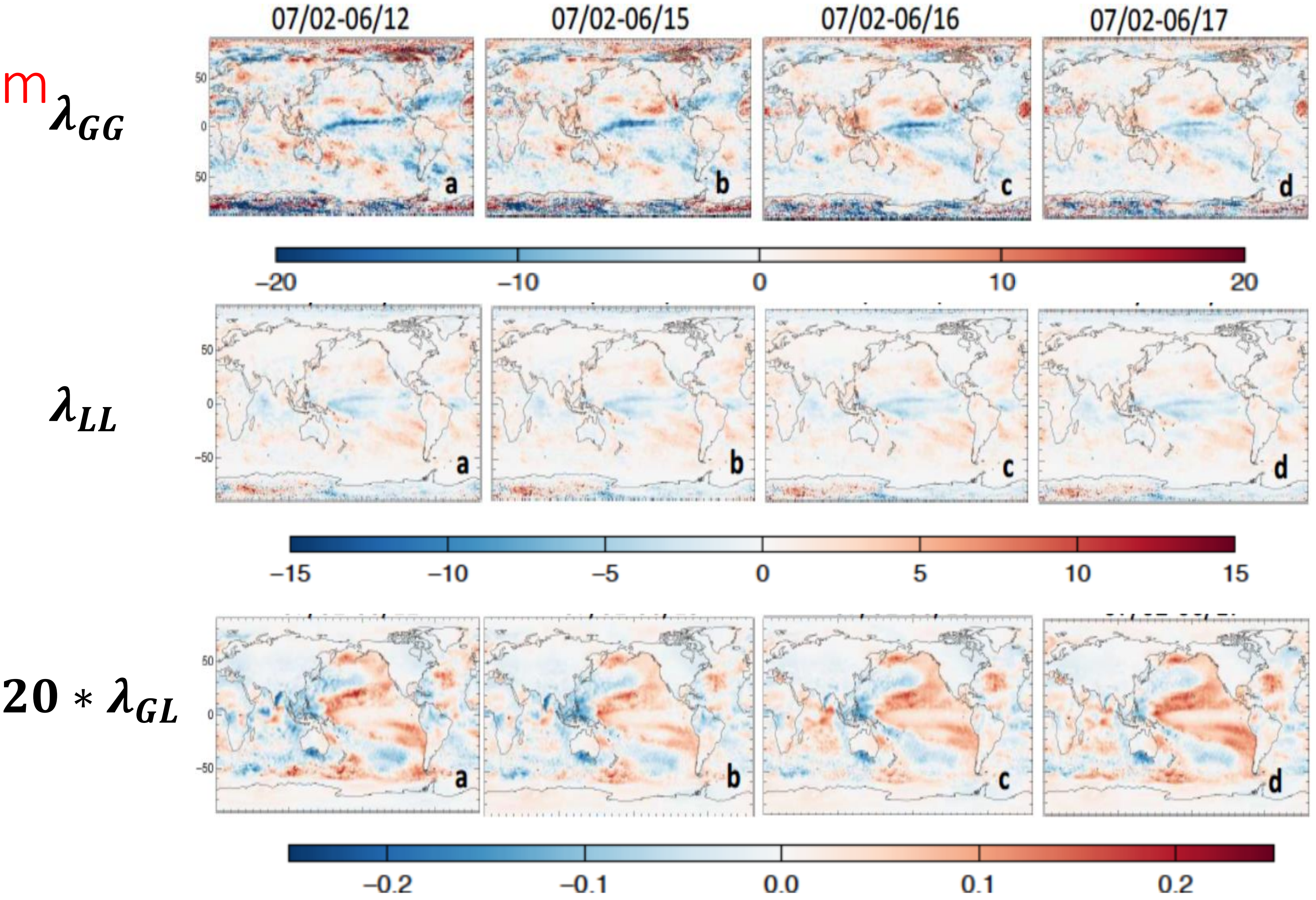
- During A-Train era, the temporal variability in λ_{GG} to interannual climate variability is contributed by both high cloud and low cloud.
- Significant temporal variability in local feedback defined by λ_{GL} –> nonlocal effect included by definition.

Cloud Feedback to Interannual Climate Variability during the A-Train Era: Pattern



- Nearly time-invariant magnitude and spatial patterns of λ_{LL}.
- These conclusions also hold for different cloud types.

Net Cloud Feedback from A-Train

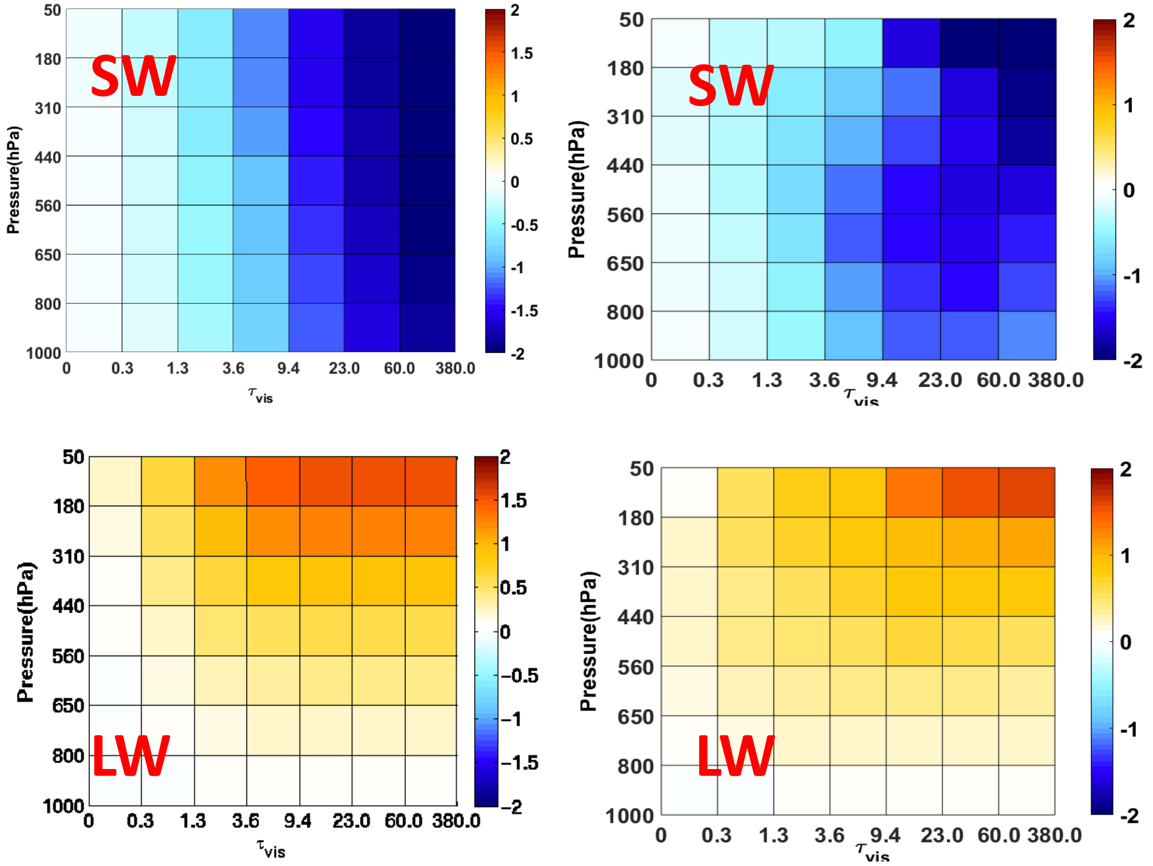


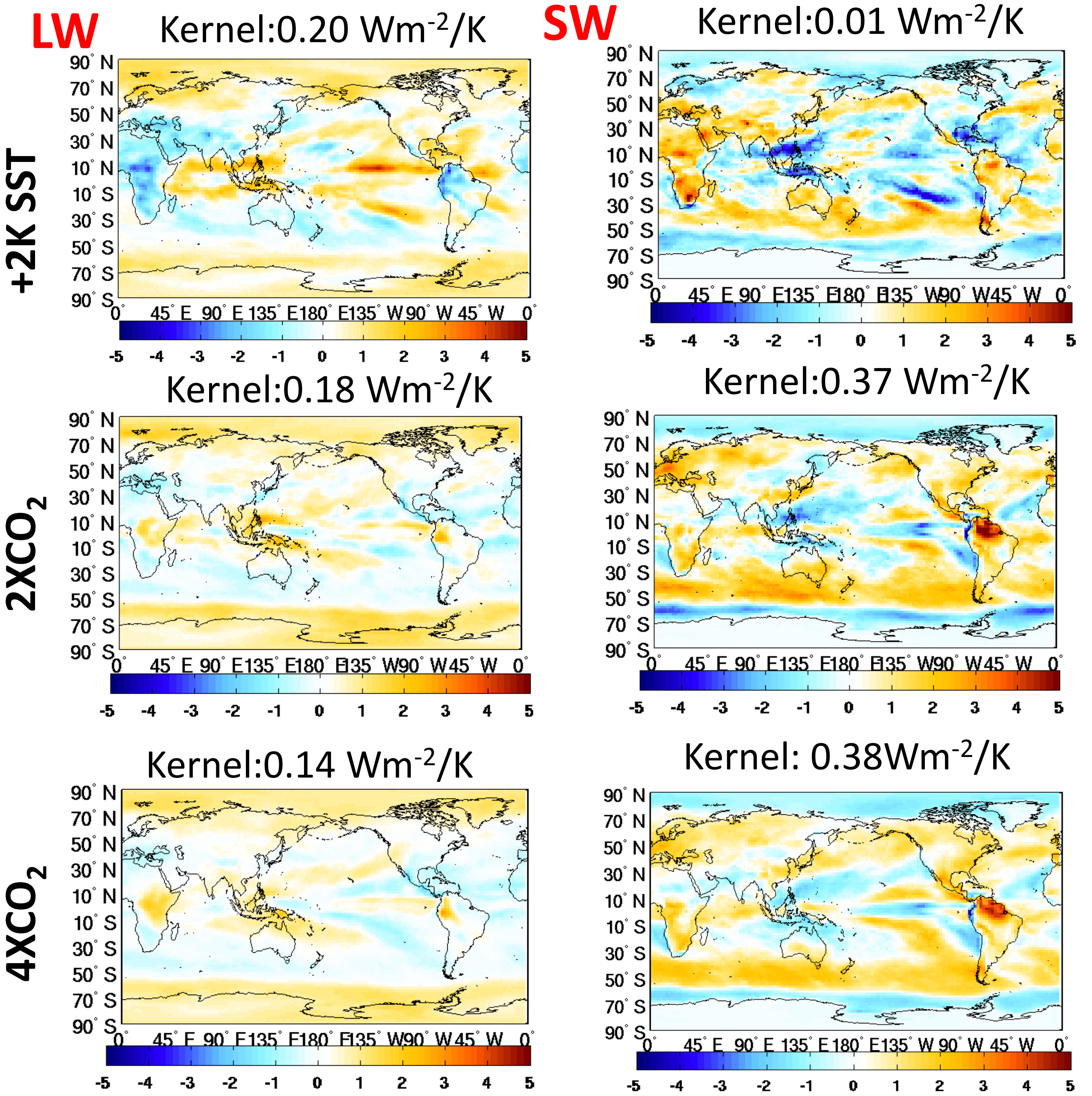
Apply the Obs-CRK Method to Climate Model Simulations

CESM version 1.1.1, CAM4, slab ocean experiment

RT-based kernel (Zelinka et al., 2012)

CESM-based kernel following Yue et al. (2016)





Summary

- Observation-based CRKs are empirically derived by cloud type from pixel-scale collocated A-Train observations and reanalysis to estimate the cloud feedback by maintaining the consistency between CRKs and cloud responses.
- Using CloudSat/CALIPSO vertical profiles of cloud calculates the uncertainty in the kernel and cloud responses.
- Different approaches to calculate cloud feedback reveal different aspect of cloud feedback and processes associated: different spatial pattern, different uncertainty ranges, and different temporal variability.
- Robust signals from current satellite observation data record to constrain the model cloud feedback.

On going research:

1. How to effectively account for the impact of observation/retrieval uncertainty in the cloud feedback calculation?
2. Robust signals from observations and model.
3. Relating cloud feedback with processes using model experiments.